

EXPERIMENTAL INVESTIGATION ON SILICON CARBIDE REINFORCED DURALUMIN BASED MMC PRODUCED BY COLD COMPACTING

GOWRI SHANKAR M. C¹, Y. M SHIVAPRAKASH^{2*}, SIDDESH KUMAR N. M³,
SIDDHARTHA M. A⁴ & AVISHEK DUTTA⁵

^{1,2}Associate Professor, Department of Mechanical and Manufacturing Engineering,
Manipal Institute of Technology, Manipal Academy of Higher Education,
Manipal, Karnataka, India

^{3,4,5}M.Tech Student, Department of Mechanical and Manufacturing Engineering,
Manipal Institute of Technology, Manipal Academy of Higher Education,
Manipal, Karnataka, India

ABSTRACT

In the present investigation, an attempt is made to fabricate the Duralumin(DA) based Silicon Carbide (SiC_p-6 and 12% wt.) reinforced composite by cold compacting the ball milled powders. The mechanically mixed powders taken into the die cavity are applied with a steady axial load in the range 22-30 T to produce the cylindrical compacts. The compacts are further subjected to sintering by holding it at a constant temperature of 580⁰C in Muffle furnace for 5 h and allowed to cool in the same for 18 h. The hardness of sintered composite is found to have improved as compared to the sintered duralumin compact prepared under similar process conditions. The SEM images showed the uniform distribution of the reinforcements in the matrix and the elemental composition is confirmed by the EDAX spectrum. The sintered specimens were further subjected to age hardening heat treatment. Specimens were soaked at 550⁰C for 2 h followed by water quenching at room temperature. The quenched specimens were artificially aged in the furnace at temperatures of 100, 150, and 200⁰C for various durations of time. The peak hardness obtained because of aging heat treatment is found to be much better than the corresponding sintered compacts. Compacts peak aged at 100⁰C exhibited better tensile strength than the other category of specimens. The composites developed in the present study would be most suitable in the applications requiring high strength and resistance to heat and wear.

KEYWORDS: Duralumin, Silicon Carbide, Compacting, Sintering & Aging

Received: Jan 25, 2019; **Accepted:** Feb 15, 2019; **Published:** Mar 13, 2019; **Paper Id.:** IJMPERDAPR201949

INTRODUCTION

Aluminium and its alloys have been extensively preferred for many applications because of their excellent mechanical properties. They are the first choice of researchers and engineers because of their low density, good heat and electric conductivity, resistance to corrosion and high endurance [1]. Addition of compatible reinforcements even in small quantities would further enhance the stiffness, hardness, fatigue resistance and tribological properties of aluminum alloys in specific [2]. In the present day scenario, aluminum based composites are being used in automobile, aerospace, marine and defense industries because of their superior properties [1, 3]. Even with the various available methods like stir casting, pressure infiltration etc. to produce metal matrix composite Powder Metallurgy (PM) has been the most popular technique, as it is simple and flexible in terms of

designing the constituents [4]. The PM method greatly avoids the formation of reinforcement clusters on the matrix and reaction between the reinforcement and matrix. PM route is advantageous as higher quantity of reinforcement can be dispersed in the matrix, and also a better control of microstructure phases is achievable [5]. Also in specific, aluminum powder metallurgy combines the superior properties of Al with the ability of powder metallurgy (PM) to produce high performance, net- or near-net-shaped parts, thus reducing or eliminating the capital and operating costs associated with intricate machining operations [6]. Of the many types of particulate reinforcements in developing metal matrix composites, SiC particulates have been found to be effective in bringing a reduction in the density of the composite in comparison to the base matrix. The reduced density and enhanced strength is a major factor in providing high strength to weight ratio of the composites [7]. Other advantages of using SiC particulates as dispersions are improved stiffness, heat conductivity, resistance to wear and fatigue, and lower thermal expansion. SiC are attractive as reinforcements because of their lower cost and lower density [8].

In the present investigation, an attempt is made to develop the composite by dispersing the SiC particles in different proportions in duralumin matrix by employing the cold compacting approach. The composite developed is expected to provide superior mechanical properties.

INVESTIGATION METHODOLOGY

Matrix and Reinforcement Powders

Duralumin powder is used as the matrix material in the present work, and is supplied by Varsha bullion & elemental analab, Mumbai. The average particle size of the duralumin powder is 50 microns and is irregular in shape. The apparent density is found to be 1.2448 g/cc. The elemental composition of this material has been shown in Table 1. As seen from the table, the major alloying element in duralumin is copper with 3.9% wt. This matrix provides an excellent combination of strength and damage tolerance at elevated and cryogenic temperatures [9]. Duralumin is extensively used for aircraft components like fittings, couplings, transmission shafts and for gears. The morphology of powder particles is shown in the SEM micrograph (figure 1). SEM micrographs are captured by scanning electron microscope (EVO MA18 with Oxford EDS(X-act)) having magnification 1X and maximum 100000X.

Table 1: Elemental Composition of Duralumin Powder

Element	Si	Fe	Cu	Mn	Mg	Al
% wt.	0.142	0.192	3.9	0.5	1.22	94.0075

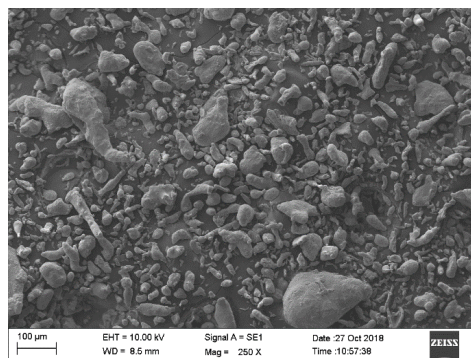


Figure 1: SEM Image Showing Morphology of Duralumin Particles

SiC used as reinforcement is a dark grey colored hard refractory material with particle size in the range 35-40

microns. The apparent density is found to be 1.158 g/cc. SiC is borrowed from Indian Fine Chemicals, Mumbai. SiC particulates exhibits a high hardness, good thermal conductivity, shock resistance and lower thermal expansion [7]. Also, these are highly wear resistant and have good mechanical properties such as high temperature strength [10]. The morphology of SiC particles and its XRD spectrum are as shown in figure 2. This image depicts that the SiC particles are in irregular shape, some with sharp edges. The XRD spectrum confirms the SiC particles. Rigaku miniflex (5th gen) X-Ray Diffractometer (XRD) instrument is used to capture the spectrum.

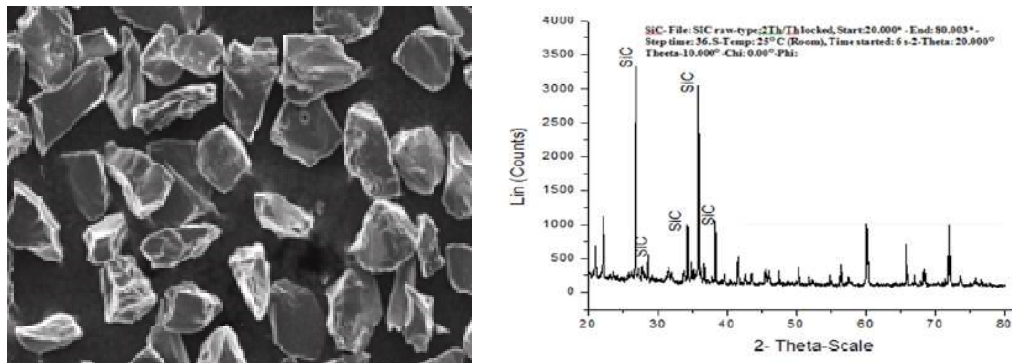


Figure 2: SEM Image showing Morphology of SiC Particles and the XRD Spectrum of SiC Particles

Production of Specimens

Tooling Details

The tooling used for cold compacting includes simple die and punches and are as shown in figure 3. The length to diameter ratio of the die is maintained as 4 in the design. The die has been fabricated from En24 steel and the punches from En8 material. In order to induce adequate strength, the die and punches were subjected to heat treatment after machining and TIG welding operations.



Figure 3: L to R-Lower Punch, Die Block and Upper Punch

Blending of Powders

The duralumin and SiC powders are mechanically mixed in a ball milling equipment [2]. The equipment pre-loaded with steel balls is charged with two types of powders such that Ball to Charge ratio (BCR) is 5:1. This ratio is essential for obtaining the homogeneous mixture of powders [11]. The powders are milled for 60 min and at a constant speed of 200 rpm in the laboratory conditions. Because of the impact of balls on the powdery charge, the powders get cold welded and hence a homogeneous mixture is obtained. The steel balls used in milling and milling equipment are shown in figure 4.

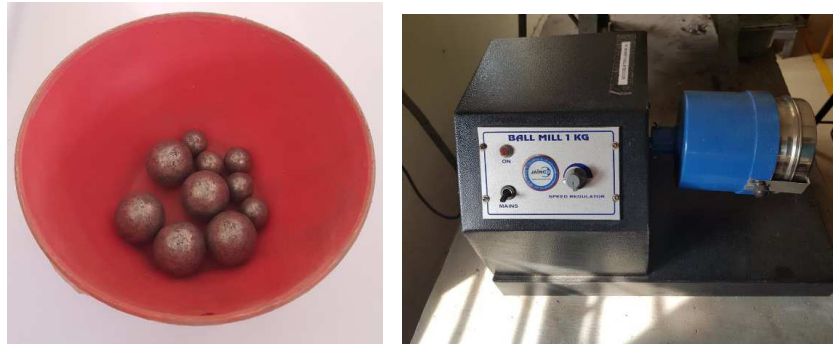


Figure 4: Steel Balls used in Milling (L) and the Ball Milling Equipment for Milling of Powders(R)

Compacting

In order to apply the load on powders to compact them, UTM of 60 T capacity is used. The steadily increasing load is axially applied through the punch as shown in figure. The compacts of duralumin and composite (6% and 12% wt.) were produced with an applied load in the range 22-30 T. In order to avoid the seizure of compact in the die and to prevent the direct surface contact between the punch and die, the surfaces of the tools are applied with a layer of zinc stearate paste. Each of the compacted specimens was removed undamaged from the die cavity by a simple ejection system that is as shown in figure 5. Some amount of minute surface cracks was observed for green composite with SiC. The exposure of SiC particles on to the hard inside die surface might have led to higher friction by breaking the lubricant, and eventually SiC particles might have slipped (inter particle bond breakage) from the surface leading to surface cracks. The Table 2 gives the details of the compacted specimens. The process of compacting the powders in UTM is as shown in figure 5 and the green compact of duralumin and that of composites are shown in photographs of figure 6.

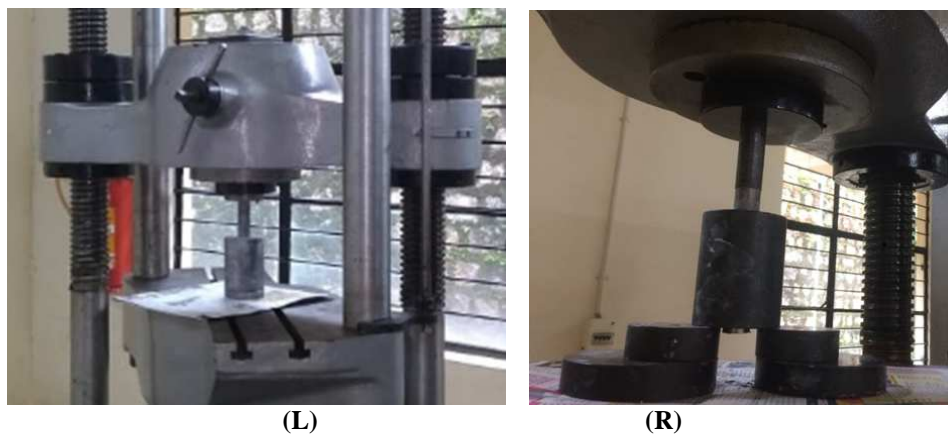


Figure 5: The Process of Compacting in UTM and Ejection of Compact Specimen from Die

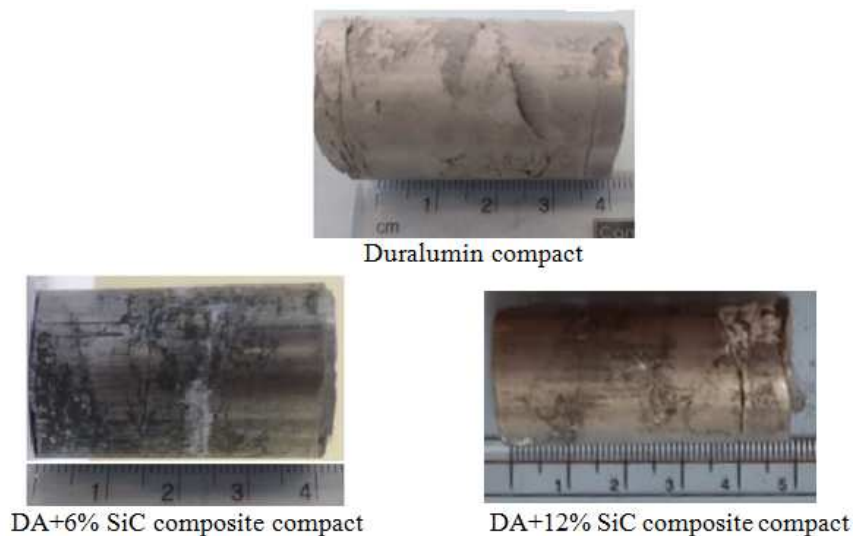


Figure 6: Green Compacts Ejected from Die Cavity

Table 2: Details of Green Compacts

Sl. No	Specimen Code	Duralumin (% wt.)	SiC (% wt.)	Compaction Load (Ton)	Dimensions of Green Compact (D cm X L cm)*
1	DA	100	0	30	$\Phi 2.3 \times 4.2$
2	DA+6% SiC	94	6	26	$\Phi 2.3 \times 4.1$
3	DA+12% SiC	88	12	22	$\Phi 2.3 \times 4.9$

*(D: Diameter & L: Length)

Sintering of Compacts

The green compacts will not have sufficient strength to withstand the external load, hence in the present study they were subjected to sintering operation in a PID controlled muffle furnace. The compacts are held at 580°C for 5 h in the furnace and then allowed to cool in the furnace itself for 18 h. The surface oxidation of compacts is prevented by loading them into furnace after the inside temperature was stabilized. The process of sintering mainly brings about the bonding between powder particles at the contact areas and thus enhances overall strength of compact [9]. At the atomic level, sintering process provides extra bonding between atoms and the atomic diffusion takes place and welded areas formed during compaction will increase the connection [12].

Experimental Details

Density and Hardness Test on Compacts

The density of the compacts was found out by electronic weighing balance (having accuracy of 0.0001 g) by adopting Archimedes' principle according to ASTM B311-08[9, 12, 13]. The theoretical density is found out as per the rule of mixtures. The specimens of DA, DA+ 6% and DA+12% are further cut into smaller cylinders in the wire EDM machine. The process of parting is shown in figure 7 and the specimens for hardness test are as shown in figure 8. The 400, 600, 800, and 1000 grit emery paper was used to reduce the scratches and to get mirror finish on the test surface. The test was done at ambient temperature (30°C) and the hardness was measured at four locations on the surface of each sample to find the average hardness. In order to measure the hardness of specimens, micro Vickers hardness tester was used [2,12,13] (Make: MATSUZAWA, Model: MMT-X7A, Capacity: Min. 5 gf and max. 1000 gf), with diamond indenter to make indentation on the surface of specimens. A dwell time of 15 secs is maintained after the application of load 100gf. The density of

compacts, porosity levels therein and their corresponding hardness values in sintered condition are tabulated in Table 3.



Figure 7: Parting Process in Wire Cut EDM



Figure 8: Sample Specimens for Hardness Test Obtained by Parting in Wire Cut EDM

Table 3: Properties of Duralumin and Composite Compacts

Sl. No	Specimen	Theoretical Density (g/cc)	Green Density (g/cc)	Sintered Density (g/cc)	Relative Density (%)	% Porosity (before Sintering)	% Porosity (After Sintering)	VHN of Sintered Compacts
1	DA	2.70	2.66	2.69	99.62	1.48	0.37	28
2	DA+6% SiC	2.68	2.62	2.65	98.88	2.24	1.12	35
3	DA+12% SiC	2.61	2.51	2.53	96.93	3.46	3.06	42

Aging Heat Treatment Process

The sintered specimens were subjected to age hardening heat treatment. The heat treatment was done in a PID controlled muffle furnace. The furnace temperature was initially made stable to the required temperature and then specimens were loaded to avoid the surface oxidation. Compacts are soaked at 550°C for a span of 2 h, and then quenched in water at room temperature. Hardness was measured before starting aging process and further, compacts were artificially aged in the furnace at temperatures of 100, 150, and 200°C for various interval of time. The heat treatment curves adopted during the process cycle are depicted in figure 9.

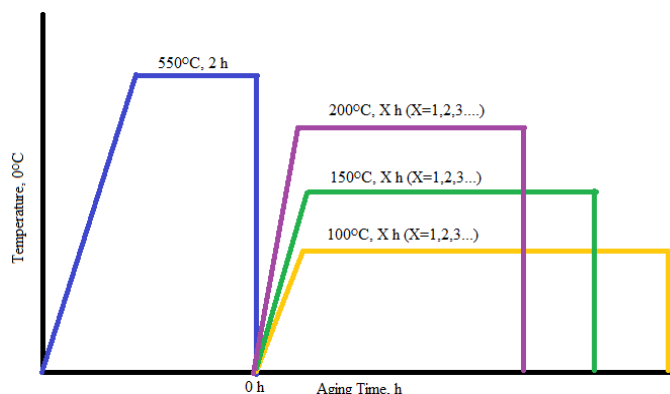


Figure 9: Heat Treatment Curves

Hardness of Aged Specimens

Hardness values are measured at time interval of 60 minutes, to determine the peak aging time for that specific temperature. The hardness for each interval is tabulated for all the three types of compacts carried at 100, 150 and 200°C are given in Tables 4-12. Comparison of peak hardness of specimens under different conditions has been given in Table 13.

Table 4: Hardness Values of DA Specimen Aged at 100°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	25	25	28	30	31	33	35	37	38	40	42	47	50	56	52	48	---	---

Table 5: Hardness Values of DA+6% SiC Composite Aged at 100°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	30	32	36	40	45	50	55	56	58	60	64	60	---	---	---	---	---	---

Table 6: Hardness Values of DA+12% SiC Composite Aged at 100°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	38	40	46	53	59	65	75	70	65	---	---	---	---	---	---	---	---	---

Table 7: Hardness Values of DA Specimen Aged at 150°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	25	27	29	30	32	34	36	38	40	42	44	48	49	45	43	---	---	---

Table 8: Hardness Values of DA+6% SiC Composite Aged at 150°C for Different aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	30	34	36	38	40	42	45	46	48	55	50	46	---	---	---	---	---	---

Table 9: Hardness Values of DA+12% SiC Composite aged at 150°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	38	40	48	55	64	69	65	60	---	---	---	---	---	---	---	---	---	---

Table 10: Hardness Values of DA Specimen Aged at 200°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	26	28	30	31	33	35	38	39	41	42	43	41	39	---	---	---	---	---

Table 11: Hardness Values of DA+6% SiC Composite Aged at 200°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	30	34	36	40	42	44	47	49	50	48	45	---	---	---	---	---	---	---

Table 12: Hardness Values of DA+12% SiC Composite Aged at 200°C for Different Aging Times

Sample No	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aging Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VHN	38	48	54	59	62	60	55	---	---	---	---	---	---	---	---	---	---	---

Table 13: Comparative Tabulation of Peak Hardness of Specimens under Different Conditions

Condition	Duralumin(DA)	DA+6% SiC	DA+12% SiC
Sintered	28	35	42
Peak aged at 100°C	56	64	75
Peak aged at 150°C	49	55	69
Peak aged at 200°C	43	50	62

Tension Test

The tensile test specimens were fabricated from the cylindrical peak hardened compacts as per E8/E8M-13a standard [14]. The tensile test was carried out in a Tensometer which was computer integrated to generate the on line plot of load-vs-extension. The results of tensile test conducted on as sintered and peak aged specimens are shown in Table 14.

Table 14: Tensile Properties of Duralumin and Composite Compacts

Sl. No	Specimen	Ultimate Tensile strength (MPa)			
		As sintered	100°C	150°C	200°C
1	DA	90	135	121	110
2	DA+6%	103	156	143	132
3	DA+12%	112	170	162	155

RESULTS AND DISCUSSIONS

Density of Compacts

The porosities of the compacts were known by the difference between the calculated and measured densities of each composite. The theoretical densities were also calculated depending on the weight fraction of the reinforcement and matrix. The lowest density was observed in the cold compact samples due to being not yet fully processed before sintering. The density of the compacts reduced with increasing in quantity of SiC which is because of lower density of SiC particles compared to DA. This can be also attributed to increased porosity rate depending on the increasing weight fraction of the SiC reinforcement in the matrix, as reported in [1]. The variation of density with the quantity of SiC has been depicted in Figures 10-11. Relative density is calculated by using the relation, Relative density = sintered density/theoretical density [14]. The green density is observed to be increasing with the increase in compacting load, which is shown in Figure 12. As seen in Figure 13, more porosity is induced at higher quantity of reinforcements, this may be due to the increase in surface area of SiC reinforcement particles.

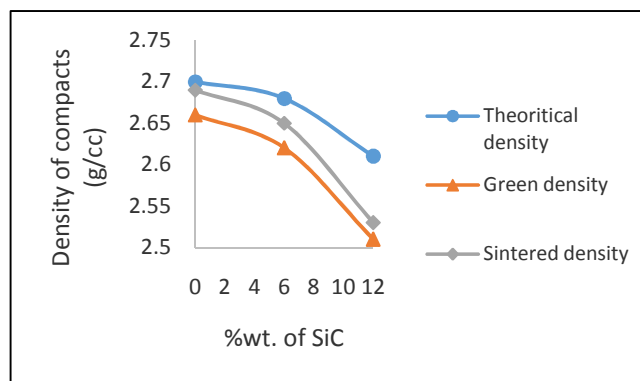


Figure 10: Variation of Density of Compacts with the Amount of SiC Dispersion in the Matrix

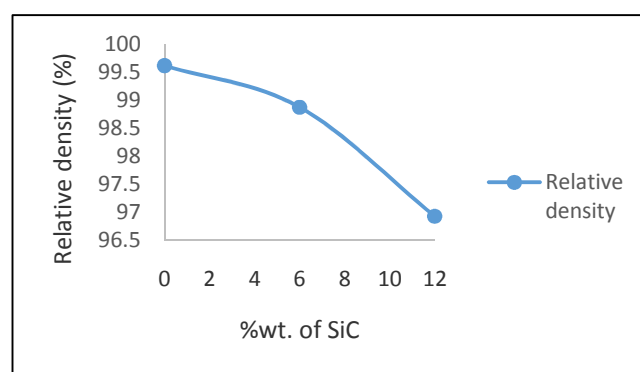


Figure 11: Variation of Relative Density of Compacts with the Amount of SiC

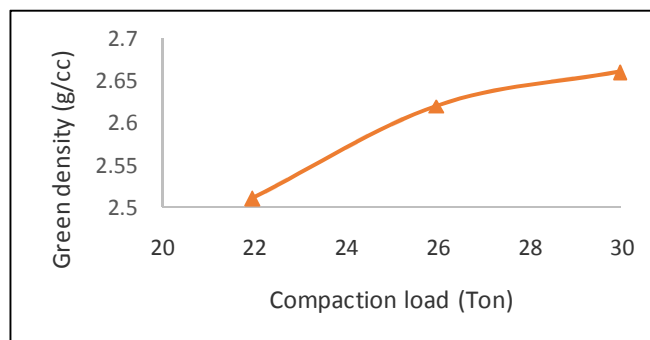


Figure 12: Variation of Green Density of Compacts with Compaction Load

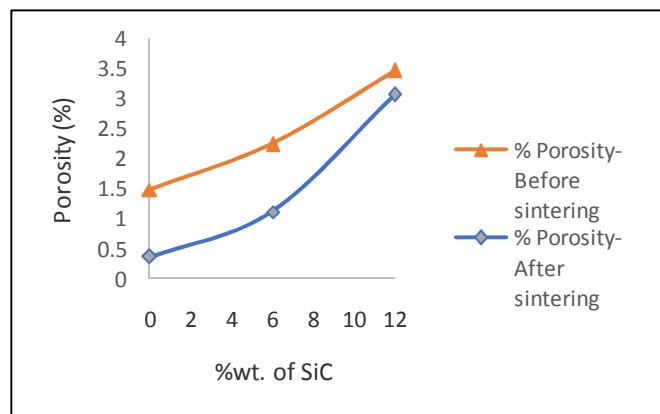


Figure 13: Variation of Porosity Level in Compacts with Increase in the Quantity of SiC Reinforcement

Microstructure Study on Sintered Compacts

Micrograph shown in Figure 14 reveals that there is fairly uniform distribution of SiC particles throughout the matrix alloy with very minimal surface porosity or cracks. Also, it appears to be a good bonding between the matrix and the reinforcement particulates that could certainly result in better load transfer from the matrix to reinforced material. As observed from the micrograph, there is no agglomeration of reinforcements in the matrix, which is very common in the liquid state processing techniques. Figure 15 shows the EDAX spectrum taken on sintered composite compact which confirms the elemental composition.

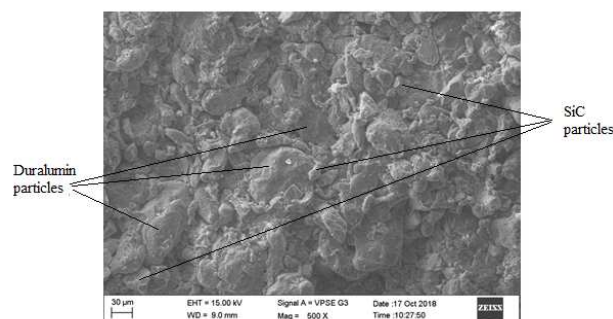


Figure 14: SEM Micrograph of Sintered Composite Compact Confirming the Uniform Distribution of SiC (12% wt.) in the Matrix Phase

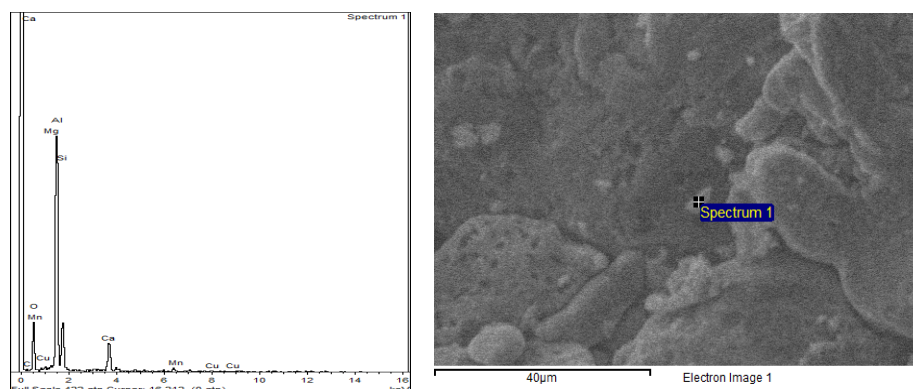


Figure 15: EDAX Spectrum taken on Sintered Composite Compact Confirming the Presence of SiC in the Matrix Phase

Hardness in Sintered and Aged Condition

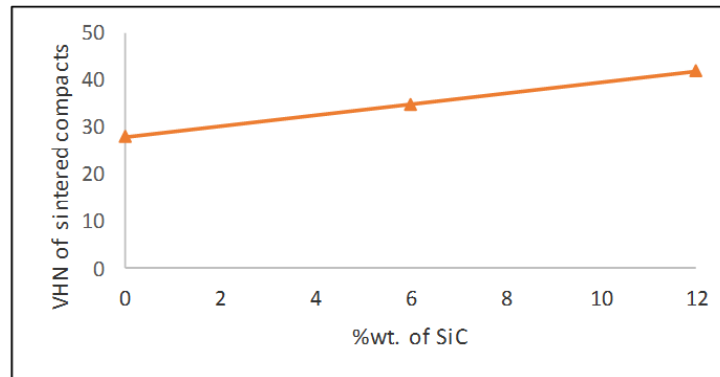


Figure 16: Variation of VHN of Compacts with the Quantity of Sic

As can be seen in Figure, as the amount of reinforcement is increased in matrix the hardness of composite will also increase. Both DA and DA-6% and 12% wt. aged samples are subjected to hardness measurement (VHN). Variation of hardness with aging temperature and duration for the above composites are shown in Figures 17-22. Hardness is found to increase gradually with time for both the DA and its composites. It reaches to peak hardness value followed by over-aging that result in decrease of hardness [15]. The hardness increases with increase amount of SiC particulates. The increase in hardness is due to the presence of hard dispersions that positively contributes to the hardness of the composites [16]. Since matrix is strong age hardenable alloy, it is expected that SiC reinforced DA alloy composites may be too sensitive to age hardening irrespective of aging temperatures. Among all the aging temperatures, aging at 100°C for both base alloy and its composites show higher peak hardness values although the time intervals for achieving peak aging are considerably higher. Lower temperature aging (100°C) contributes to the increased hardness due to escalation in the number of intermediate zones during precipitation, increased number of finer intermetallics and decreased interparticle distances. The hardness value decreases after peak aging condition, may be due to coarsening of intermetallic precipitates which form during aging and existence of incoherency between matrix and intermetallics termed as over-aging [17]. Higher temperatures (150 and 200°C) accelerate the aging rate due to the enhanced rate of diffusion in the matrix. Higher the aging temperature, lower is the time required to attain peak hardness [15]. Comparison of variation of hardness with quantity of SiC for sintered condition and for different aging temperatures is shown in Figure 23.

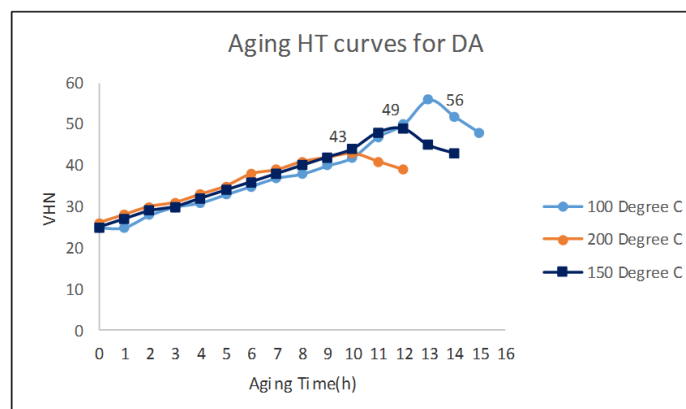


Figure 17: Variation of Hardness with Aging Time for Bare Duralumin Compact

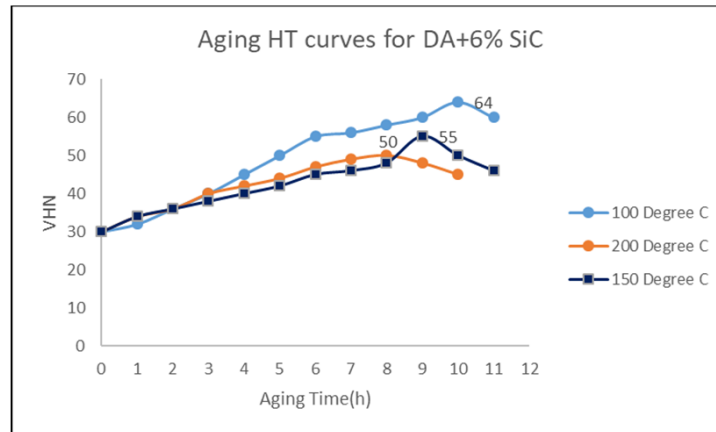


Figure 18: Variation of Hardness with Aging Time for Da+6% Sic Composite Compact

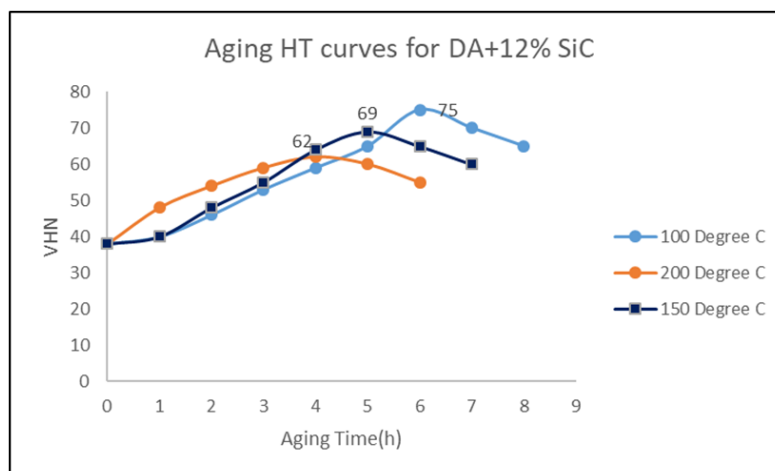


Figure 19: Variation of Hardness with Aging Time for Da+12% Sic Composite Compact

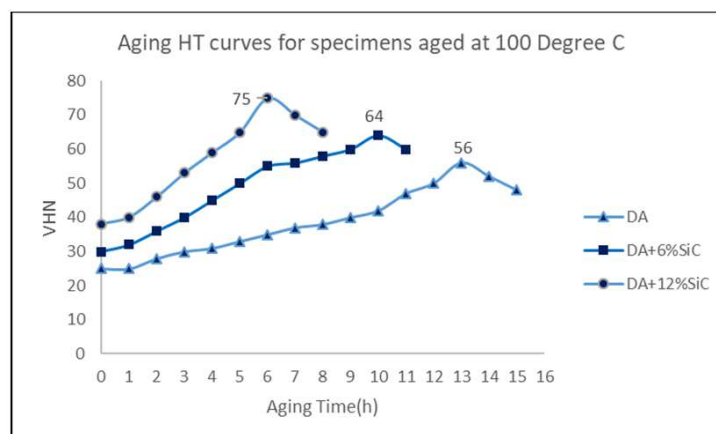


Figure 20: Comparison of Variation of Hardness with Aging Time for All Category of Compacts Aged at 100°C

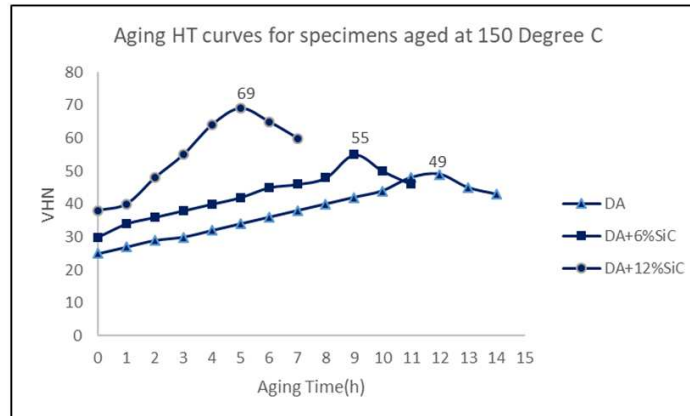


Figure 21: Comparison of Variation of Hardness with Aging Time for All Category of Compacts Aged at 150^oc

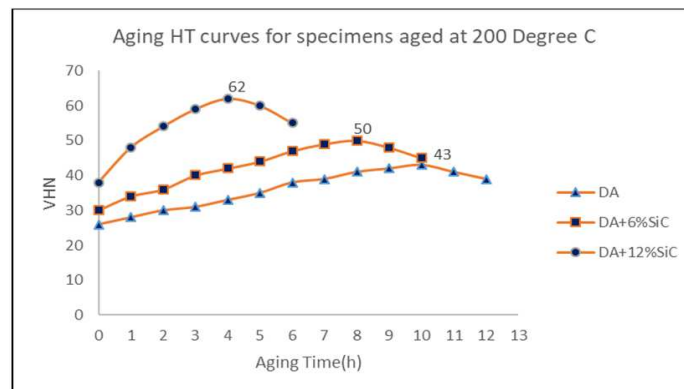


Figure 22: Comparison of Variation of Hardness with Aging Time for All Category of Compacts Aged at 200^oc

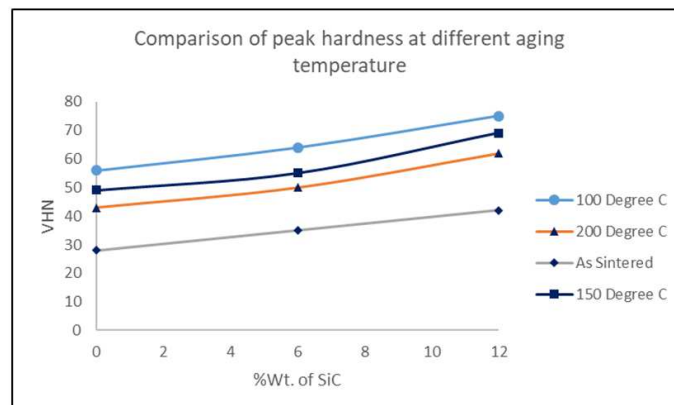


Figure 23: Comparison of Variation of Hardness With Quantity of Sic for Sintered Condition and for Different Aging Temperatures of Compacts

Tension Test

The specimens are observed to have undergone primarily the ductile fracture, with cup and cone shape formed on the fractured halves of the specimens. Tensile test is carried out on DA and peak aged samples. Figure 24 shows the comparison of variation of UTS with quantity of SiC for sintered condition and for different aging temperatures of compacts. Presence of hard ceramic particles in ductile matrix results in combination of metallic properties (ductility and

toughness) and ceramic characteristics (high hardness and Young's modulus). Uniform distribution of the reinforcement particles is of crucial importance for high performance engineering applications such as automotive and aircraft industries. A homogeneous distribution of individual and hybrid reinforcements is essential to improve the mechanical properties of the composites by strong interface bonding, which transfers and distributes the load from the matrix to the reinforcements exhibiting increased elastic modulus and strength. The increase in tensile strength by the presence of hard secondary phases on soft matrix leads to alloy strengthening, which also helps to decrease grain size of the matrix resulting further improvement of mechanical properties [18, 19]. Higher particle concentration and lower aging temperature result in higher dislocation density and dislocation particle interactions. When load is applied, presence of the hard particles and intermetallics contribute to dislocation pileup, increasing back stress, and work hardening the matrix due to constrained plastic flow in the ductile matrix. The synergetic effect of dislocation interaction with the reinforcement, intermetallic and grain boundary provides a positive contribution to alloy strengthening [20,21].

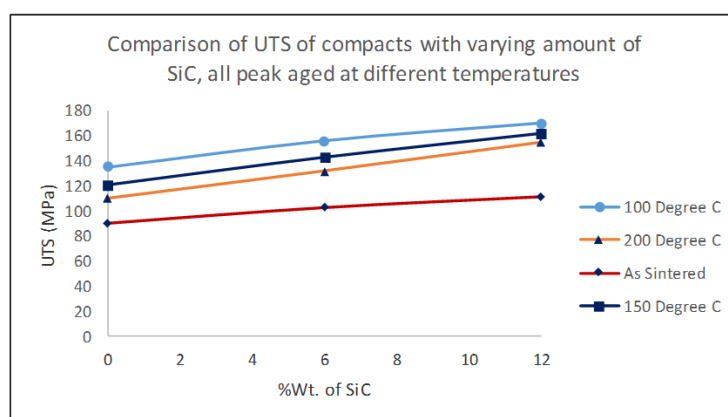


Figure 24: Comparison of Variation of UTS with Quantity of Sic for Sintered Condition and for Different Aging Temperatures of Compacts

Fractography

The fractured surface of all the three specimens in common indicates the presence of pores and a ductile fracture. The pores are observed to be more for composite compacts with 12% wt. of SiC as compared to 6% wt. SiC composite. Also, cleavage cracking was prevalent in the material. The cleavages cracking coupled with an inter granular micro-void are found to be dominant. There is even coalescence of voids, which resulted in bigger voids. It is found from Figure 25 (a) that the dimple rupture is predominant. Numerous cuplike depressions are observed and these are referred as dimples as shown in Figure 25(b) at higher magnification. It is found that some micro-voids are formed at grain boundary (GB) and other locations. The presence of river pattern is the indication that the fracture is fully ductile in nature. Figure 25 (b & c) shows fracture surface of aged specimen after tensile fracture. Here, dimple density is more and smaller in size indicating the formation of more number of micro-voids (dimples after coalescence) at numerous precipitated particles in peak aged condition. Therefore, the dimples are evenly distributed with smaller size.

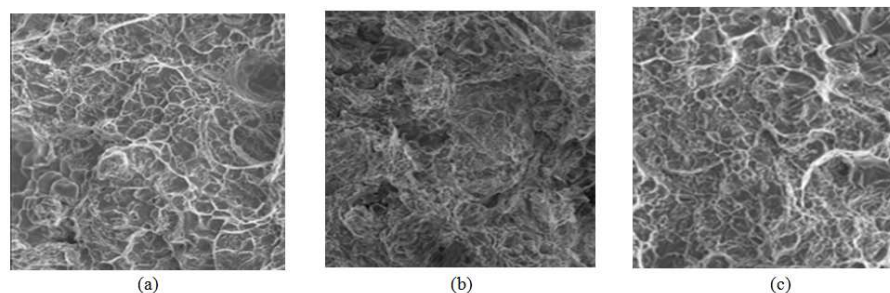


Figure 25: Fractured Surface of Peak Aged Specimens of (a) Da (b) Da+6% Sic and (c) Da+12% Sic

CONCLUSIONS

On the basis of results of experiments, the following points are concluded:

- The compacts of duralumin and composites (with 6 and 12% wt. SiC dispersed in duralumin) were successfully fabricated by adopting uniaxial cold compacting approach.
- The SEM images confirmed uniform distribution of SiC in the composites.
- The density of the compacts decreased with increasing the weight fraction of SiC reinforcement as expected due to the lower density of SiC particles compared to duralumin.
- More porosity is induced at higher quantity of reinforcements; this may be due to the increase in surface area of SiC reinforcement particles.
- Hardness is found to increase gradually with time for both the DA and its composites. It reaches to peak hardness value followed by over-aging that result in decrease of hardness. This may be due to coarsening of intermetallic precipitates which form during aging and existence of incoherency between matrix and intermetallics, termed as over-aging.
- Higher aging temperatures (150 and 200°C) accelerate the aging rate due to the enhanced rate of diffusion in the matrix, hence higher the aging temperature, lower is the time required to attain peak hardness.
- Compacts peak aged at 100°C exhibited better tensile strength than the other category of specimens' peak aged at higher temperature. Also, the presence of higher amount of hard SiC particles in ductile matrix resulted in the higher hardness, which slightly reduced UTS of composite compacts as compared to DA compacts.

REFERENCES

1. Halil Karakoça, Şener Karabulut & Ramazan Çitak (2018). Study On Mechanical And Ballistic Performances Of Boron Carbide Reinforced Al 6061 Aluminum Alloy Produced By Powder Metallurgy, *Composites Part B* 148 68–80.
2. Prashantha Kumar H. G & Anthony Xavier. M (2017). Assessment Of Mechanical And Tribological Properties Of Al 2024-Sic-Graphene Hybrid Composites, *Procedia Engineering* 174, 992 – 999.
3. Naiqin Zhao, Philip Nash & Xianjin Yang (2005). The Effect Of Mechanical Alloying On Sic Distribution And The Properties Of 6061 Aluminum Composite, *Journal Of Materials Processing Technology* 170, 586–592.
4. X. Z. Zhang, T. J. Chen & Y. H. Qin (2016). Effects Of Solution Treatment On Tensile Properties And Strengthening Mechanisms Of Sicp/6061al Composites Fabricated By Powder Thixoforming, *Materials And Design* 99, 182–192.

5. S. Sivasankaran, K. Sivaprasad, R. Narayanasamy & Vijay Kumar Iyer (2010). An Investigation On Flowability And Compressibility Of Aa 6061100–X-X Wt.% Tio₂ Micro And Nanocomposite Powder Prepared By Blending And Mechanical Alloying, *Powder Technology* 201, 70–82.
6. M. A. Jabbari Taleghani, E. M. Ruiz Navas & J. M. Torralba (2014). Microstructural And Mechanical Characterisation Of 7075 Aluminium Alloy Consolidated From A Premixed Powder By Cold Compaction And Hot Extrusion, *Materials And Design* 55, 674–682.
7. Y. M. Shivaprakash, Anunoy Sarkar, Sunit Jha, Muktesh Singh & Shachin Bangera (2018). Experimental Studies On Sic And Rice Husk Ash Reinforced Al Alloy Composite,, *Matec Web Of Conferences* 144, 02002.
8. Dr. Shivaprakash Y. M, Gurumurthy B. M, Dr. S. S. Sharma, Jayashree P. K & Gowrishankar M. C (2015). Production, Testing And Microstructural Investigation On Fly Ash Reinforced Aluminium Alloy Matrix Composite, *International Journal Of Applied Engineering Research* Issn 0973-4562 Volume 10, Number 20, Pp 41583-41590.
9. P. Ravindran, K. Manisekar, P. Rathika & P. Narayanasamy(2013). Tribological Properties Of Powder Metallurgy – Processed Aluminium Self Lubricating Hybrid Composites With Sic Additions, *Materials And Design* 45, 561–570.
10. Km, A. F., & Varghese, S. (2014). Behavioural Study Of Steel Fiber And Polypropylene Fiber Reinforced Concrete. *Int. J. Res. Eng. Technol.*, 2(10).
11. Y M Shivaprakash¹, H C Ramu, Chiranjivee, Roushan Kumar & Deepak Kumar (2018). Experimental Studies On Al (5.7% Zn) Alloy Based Hybrid Mmc, *Iop Conf. Series: Materials Science And Engineering* 310, 012004.
12. Anil Kumar Bodukuria, K. Eswaraiab, Katla Rajendara & V. Sampath (2016) Fabrication Of Al–Sic–B₄C Metal Matrixcomposite By Powder Metallurgy Techniqueand Evaluating Mechanical Properties, *Perspectives In Science*, 8, 428–431.
13. Ramaswamy, R., Selvam, B., Marimuthu, P., & Elango, N. (2018). Investigation Of Densification Behavior On Yttrium Oxide-Reinforced Ti–6Al–4V Nano-Composite Through Powder Metallurgy. *Int. J. Mech. Prod. Eng. Res. Dev.*, 8(2), 433-442.
14. Muhammad Irfan Ab Kadir, Mohammad Sukri Mustapa, Noradila Abdul Latifa & Ahmed Sahib Mahdia (2017). Microstructural Analysis And Mechanical Properties Of Direct Recycling Aluminium Chips Aa6061/Al Powder Fabricated By Uniaxial Cold Compaction Technique, *Procedia Engineering* 184, 687 – 694.
15. H. M. Zakaria (2014). Microstructural And Corrosion Behavior Of Al/Sic Metal Matrix Composites, *Ain Shams Engineering Journal*, 5, 831–838.
16. Mahdi Dehestani, Erik Adolfsson & Lia A. Stanciu (2016). Mechanical Properties And Corrosion Behavior Of Powder Metallurgy Iron-Hydroxyapatite Composites For Biodegradable Implant Applications, *Materials And Design* 109, 556–569.
17. Rajasekaran, S, Udayashankar, N. K & Nayak, J (2012). T4 And T6 Treatment Of 6061 Al-15 Vol.% Sic Composite. *Isrn Materials Science*, 1-5.
18. Kumar G. V, Rao, C. S. P, Selvaraj, N., & Bhagyashekar, M. S (2010). Studies On Al6061-Sic And Al7075-Al₂O₃ Metal Matrix Composites. *Journal Of Minerals And Materials Characterization And Engineering*, 9(1), Pp.43-55.
19. Rafiq, A. S, Abdullah, H. A, & Al-Belushi, K. R (2000). Influence Of Aging Parameters On The Mechanical Properties Of 6063 Aluminium Alloy. *Journal Of Materials Processing Technology*, 102(1), Pp.234-240.
20. Ibrahim, M. F, Ammar, H. R., Samuel, A. M., Soliman, M. S, Almajid, A, & Samuel, F. H (2014). Mechanical Properties And Fracture Of Al–15 Vol.% B₄C Based Metal Matrix Composites. *International Journal Of Cast Metals Research*, 27(1), Pp.7-14.

21. Auradi, V., Rajesh, G. L., & Kori S. A (2014). *Processing Of B4c Particulate Reinforced 6061aluminum Matrix Composites By Melt Stirring Involving Two-Step Addition*. *Procedia Materials Science*, 6, Pp.1068-1076.
22. Milan, M. T. & Bowen P (2004). *Tensile And Fracture Toughness Properties Of Sicp Reinforced Al Alloys: Effects Of Particle Size, Particle Volume Fraction, And Matrix Strength*. *Journal Of Materials Engineering And Performance*, 13(6), Pp.775-783.
23. Ahn, H. K & Yu, C. H. (2001). *Effect Of Sic Volume Fraction On The Age-Hardening Behavior In Sic Particulate-Reinforced 6061 Aluminum Alloy Composites*. *Metals And Materials International*, 7(1), Pp.1-7.

